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(71) Applicant: AIR PRODUCTS AND CHEMICALS,
INC.
Allentown, PA 18195-1501 (US)

(72) Inventor: Sircar, Shivaji
Wescosville, PA 18106 (US)

(74) Representative: Burford, Anthony Frederick
W.H. Beck, Greener & Co.
7 Stone Buildings
Lincoln's Inn
London WC2A 3SZ (GB)

(54) Pressure swing adsorption process with a single adsorbent bed

(57) A single-bed PSA system comprising a blower (5), an adsorber vessel (13), and a gas product storage tank (21) separates a gas mixture (1) using a three-step cycle comprising adsorption, evacuation, and pressurization. Pressurization is accomplished by introducing product gas, preferably directly from the gas product

storage tank (21), into both the feed end and the product end of the adsorber vessel (13). Preferably a portion of the pressurization gas is introduced into the adsorber vessel (13) by the blower (5), which also is used for providing feed to the adsorber vessel (13) and for withdrawing gas from the adsorber vessel (13) during the evacuation step.

Description

Pressure swing adsorption is a well-known method for the separation of bulk gas mixtures and for the purification of gas streams containing low concentrations of undesirable components. The method has been developed and adapted for a wide range of operating conditions, product purity, and product recovery. Many pressure swing adsorption (PSA) systems utilize two or more adsorber beds operated in a cyclic sequence in order to maintain a constant product flow rate while selected beds undergo various steps including adsorption, depressurization, desorption, purge, pressure equalization, pressurization, and other related steps. Multiple adsorber beds using numerous process steps are required to achieve high purity and/or recovery of valuable gaseous products such as hydrogen, carbon oxides, synthesis gas, and light hydrocarbons. The high cost of generating the feed gas mixtures containing these valuable components usually justifies the complexity and capital expense of multiple-bed PSA systems.

Other gaseous products amenable to recovery by PSA do not require the high purity and/or recovery of the above-named products. In the recovery of oxygen and nitrogen from air by PSA, for example, lower purity products are acceptable for certain end uses and simpler PSA systems can be used for such products. These simpler PSA systems have significantly lower capital and operating costs than the multiple-bed systems earlier described. The simplest of these PSA systems for air separation utilize a single adsorber bed in conjunction with one or more gas storage vessels to allow constant product flow and provide gas for adsorber purge and pressurization during the regeneration portion of the PSA cycle. A number of single-bed PSA processes have been developed and are known in the art.

US-A-4,561,865 discloses a single-bed PSA system comprising an adsorber and a surge tank operated with a feed compressor in a three-step cycle. First, compressed feed air is introduced into the adsorber, which increases the pressure in the adsorber, and simultaneously adsorber effluent is withdrawn into the surge tank. A portion of the gas is withdrawn from the surge tank as an oxygen-enriched product. The adsorber feed is then discontinued and the adsorber is vented countercurrently (i.e. through the adsorber feed end) to the atmosphere. During this venting step, purge gas from the surge tank is introduced into the product end of the adsorber. Upon completion of the vent/purge step, the adsorber and the surge tank are pressure equalized through the adsorber product end (i.e. countercurrently). The steps are repeated in a cyclic manner. US-A-4,511,377 describes a modular apparatus using this PSA process.

A single-bed PSA system is described in US-A-4,892,566 which utilizes an adsorber in conjunction with a surge tank, feed compressor, and switch valves to carry out a series of steps. First, compressed feed air is introduced into the adsorber, which increases the pressure in the adsorber while at the same time adsorber effluent is withdrawn into the surge tank. A portion of the gas is withdrawn from the surge tank as an oxygen-enriched product. The adsorber feed is discontinued and the adsorber outlet closed, and the adsorber is vented countercurrently (i.e. through the adsorber feed end) to the atmosphere. Gas from the surge tank is introduced into the adsorber countercurrently (i.e. through the adsorber product end) and the pressures in the adsorber and surge tank are equalized. The adsorber is then pressurized with feed air through the feed end and pressure equalized with the surge tank. The adsorber is further pressurized to a pressure above that of the surge tank, and finally the adsorber and surge tank are pressure equalized. The steps are then repeated in cyclic fashion.

US-A-5,032,150 discloses a single-bed PSA process which utilizes multiple gas storage tanks in a PSA cycle to separate air. Compressed air is fed from an air feed tank into an adsorber presaturated with oxygen-rich gas from a previous cycle and the adsorber effluent is directed into a product collector tank, from which a portion of the gas is withdrawn as an oxygen-rich product. The adsorber outlet is then closed and the adsorber is pressure equalized with the air feed tank. Next, the adsorber is rinsed with nitrogen-rich gas from a nitrogen product tank, and the displaced gas is stored in the air feed tank. The nitrogen-saturated adsorber then is depressurized countercurrently (i.e. through the adsorber feed end) into the nitrogen product tank. Nitrogen may be withdrawn as a product if required. Finally the adsorber is purged countercurrently with oxygen-rich gas from the product collector tank to displace the nitrogen therein and then is pressurized countercurrently with the oxygen-rich gas to the adsorption pressure. The steps are repeated in a cyclic manner.

A single-vessel rapid PSA system is described in US-A-5,071,449 in which the vessel contains dual adsorption layers and operates in alternating fashion with a continuous feed gas and two continuous product streams. A product surge tank is not used. Another rapid PSA system utilizing a single adsorbent bed operating in a cycle of 30 seconds or less is described in US-A-4,194,892. The adsorber effluent optionally flows through a product surge tank to dampen flow fluctuations during adsorber cycling.

A single-bed PSA system with a product surge tank and an equalization tank is disclosed in US-A-5,370,728. In the operation of this system, compressed air feed is introduced into the adsorbent bed, pressurizing the bed from an intermediate pressure up to a maximum adsorption pressure, and the effluent product is withdrawn from the bed into the product surge tank. The adsorbent bed then is isolated and depressurized cocurrently (i.e. through the product end) into an equalization tank at the intermediate pressure. Next, the bed is further depressurized countercurrently (i.e. through the feed end) to a lower desorption pressure, and the bed is purged countercurrently with gas from the product surge tank. The bed is then pressurized countercurrently to the intermediate pressure with gas from the equal-

ization tank. Finally the bed is pressurized with feed air and the steps are repeated in a cyclic manner.

Single-bed PSA systems for generating an oxygen-enriched gas from air can be utilized efficiently as described in the art summarized above. Improvements to the simplest of these single-bed systems are advantageous and will encourage the wider use of such systems for the supply of moderate-purity oxygen or nitrogen. The invention described below and defined in the claims which follow offers an improvement to a single-bed PSA system for providing such products.

The invention is a pressure swing adsorption process for the separation of a feed gas mixture containing at least one more strongly adsorbable component and at least one less strongly adsorbable component by introducing the feed gas mixture into a feed end of an adsorber vessel containing a solid adsorbent which preferentially adsorbs the more strongly adsorbable component, withdrawing from a product end of the adsorber vessel an adsorber effluent enriched in the less strongly adsorbable component, passing the adsorber effluent into a gas storage vessel, and withdrawing from the gas storage vessel a product stream enriched in the less strongly adsorbable component. The introduction of the feed gas mixture into the adsorber vessel is terminated and the adsorber vessel is depressurized by withdrawing therefrom a depressurization gas enriched in the more strongly adsorbable component. The adsorber vessel is pressurized by introducing gas from the gas storage vessel into the feed end and the product end of the adsorber vessel, and all steps are repeated in a cyclic manner.

The feed gas mixture preferably is air, wherein the more strongly adsorbable component is nitrogen and the less strongly adsorbable component is oxygen. The solid adsorbent can be selected from NaX, NaA, CaX, and CaA zeolite or other zeolites capable of selectively adsorbing nitrogen.

The depressurization gas preferably is withdrawn from the feed end of the adsorber vessel. If desired, a portion of the product stream enriched in the less strongly adsorbable component which is withdrawn from the gas storage vessel can be used for repressurizing the adsorber vessel. Alternatively, the pressurization gas can be withdrawn directly from the gas storage vessel independent of the withdrawal of product stream from the gas storage vessel.

Typically the pressure in the adsorber vessel during introduction of the feed gas mixture is between 15 and 100 psia (100-700 kPa). The adsorber vessel preferably is depressurized to a final pressure of between 0.15 and 12 psia (1-80 kPa) before the pressurization step. The feed, depressurization, and pressurization steps may be carried out over a cycle duration of between 30 and 240 seconds.

The invention includes a pressure swing adsorption system for the separation of a feed gas mixture containing at least one more strongly adsorbable component and at least one less strongly adsorbable component which comprises an adsorber vessel containing a solid adsorbent which preferentially adsorbs the more strongly adsorbable component, wherein the vessel has a feed end and a product end; a feed blower and piping means for introducing the feed gas mixture into the feed end of the adsorber vessel; and a gas storage tank for receiving adsorber effluent withdrawn from the adsorber vessel. The system includes piping means for withdrawing from the gas storage vessel a product stream enriched in the less strongly adsorbable component, piping means for transferring adsorber effluent from the product end of the adsorber vessel to the gas storage vessel and for transferring gas from the gas storage vessel into the product end of the adsorber vessel, and piping means for transferring gas from the gas storage vessel into the feed end of the adsorber vessel. In addition, the system includes valve means for isolating the adsorber vessel from the gas storage vessel and the feed gas mixture, and also piping and valve means for withdrawing depressurization gas from the adsorber vessel.

Alternatively, the pressure swing adsorption system may include piping and valve means to enable the use of the feed blower to withdraw depressurization gas from the feed end of the adsorber vessel. If desired, the system can include piping and valve means to enable the use of the feed blower to transfer gas from the gas storage vessel into the feed end of the adsorber vessel.

The following is a description by way of example only and with reference to the accompanying drawing of presently preferred embodiments of the present invention. In the drawing:

The single Figure is a schematic flow diagram of a PSA system according to the present invention.

The simplest single-bed PSA system must include at a minimum an adsorbent bed, a product surge or storage tank, a feed blower, and the necessary piping and valves to direct gas flow during the cycle steps. The single-bed PSA system of the present invention which utilizes these components is illustrated in the single Figure. Feed air 1 typically at ambient conditions passes through open valve 3 into the suction of blower 5 in which it is compressed to a pressure between 15 and 100 psia (100-700 kPa). The compressed air feed passes through line 7, open valve 9, and inlet 11 to adsorbent vessel 13. An adsorbent which preferentially adsorbs nitrogen is packed in the vessel; this adsorbent can be a NaX, NaA, CaX, or CaA zeolite, or any other zeolite capable of selectively adsorbing nitrogen. If desired, two or more layers of different adsorbents may be used in which the first layer at the inlet end of the vessel preferentially adsorbs water and carbon dioxide and the second layer comprises the main part of the bed containing the adsorbent which preferentially adsorbs nitrogen. Aluminas, silica gels, and zeolites are adsorbent materials which preferentially adsorb water and carbon dioxide.

As the compressed feed air passes upward through adsorbent vessel 13, nitrogen is selectively adsorbed to yield

adsorber effluent gas 15 containing 50 to 95 mole% oxygen. This oxygen-enriched effluent passes through open valve 17 and line 19 into product gas storage tank 21. A portion of the oxygen-enriched gas is withdrawn from storage tank 21 to provide oxygen product 23. If oxygen product is required at a higher pressure, gas from the tank is compressed in product compressor 25. During this adsorption step, valves 27 (if used), 29, 31, and 33 are closed.

5 The adsorption step proceeds for a typical period of 5 to 60 seconds, and then is terminated by closing valves 3, 9, and 17. Withdrawal of oxygen product 23 typically continues at this point. Evacuation of adsorbent vessel 13 proceeds via line 30 by opening valves 31 and 29 while blower 5 continues to operate, thereby withdrawing void space gas and desorbing nitrogen adsorbed during the previous step. This nitrogen-enriched gas typically is vented as waste gas 35, but may be a useful product in some situations. The evacuation step continues typically for 5 to 60 seconds, and 10 reduces the pressure in adsorbent vessel 13 to between 0.15 and 12 psia (1-80 kPa). The evacuation step is terminated by closing valves 29 and 31.

In an alternative mode of operation, gas from gas storage vessel 21 is introduced into the product end of adsorber vessel 13 during at least a portion of the depressurization of the adsorber vessel, thereby purging the vessel to displace void space gas and desorbed nitrogen.

15 Adsorbent vessel 13 then is pressurized by opening valve 17 to allow oxygen-rich gas to flow from product tank 21 through lines 19 and 15 into the product end of the vessel. Simultaneously oxygen-rich gas from tank 21 is introduced through line 11 into the feed end of adsorbent vessel 13, thereby providing dual-ended pressurization in combination with gas flow through line 15. Dual-end pressurization is continued in this fashion until the pressure in adsorbent vessel 13 is between 15 and 100 psia (100-700 kPa). At the completion of the pressurization step, valves 9 and 33 (or alternatively valves 27 and 33) are closed, valves 1 and 9 are opened, and the adsorption step is repeated.

20 Pressurization gas can be introduced into the feed end of adsorbent vessel 13 according to the present invention in several ways. The preferred manner is to open valves 9 and 33 so that blower 5 transfers pressurization gas from tank 21 via line 32 into the feed end of adsorbent vessel 13. This step is preferred because repressurization can be effected rapidly and also because this allows blower 5 to be operated continuously and used for pressurization in 25 addition to feed compression and adsorbent vessel evacuation as earlier described. Alternatively, pressurization gas can be provided to the feed end of adsorbent vessel 13 by withdrawal through line 37, open valve 27, dedicated pressurization blower 39, and line 41. In another alternative, pressurization gas can be withdrawn as a portion of oxygen product 23 through open valve 27, line 43, and line 41 without the use of blower 39. In yet another alternative, pressurization gas can be provided to the feed end of adsorbent vessel 13 by withdrawal through line 37, open valve 27, 30 and line 41 without the use of dedicated pressurization blower 39. In this alternative, complete pressurization of adsorbent vessel 13 might not be achievable during the desired pressurization period. In such a situation, a short time of additional pressurization using the air feed can be used to reach the required pressure in the desired time.

The three-step PSA cycle described above can be operated with a total time cycle of between 30 and 240 seconds. The adsorption step duration preferably is between 5 and 60 seconds, the evacuation step preferably is between 15 35 and 160 seconds, and the pressurization step preferably is between 2 and 20 seconds. A typical cycle duration is 60 seconds in which the adsorption step is 15 seconds, the evacuation step is 40 seconds, and the pressurization step is 5 seconds. The dual-end pressurization of the present invention allows rapid pressurization and minimizes the duration of this step, thereby improving the overall efficiency of the PSA system. The short pressurization period helps to minimize the total cycle time, which in turn results in smaller adsorber beds for a given production rate.

40 Cyclic adsorber operation is controlled by the timed operation of the valves as described above. For the preferred embodiment in which blower 5 transfers pressurization gas from tank 21 into the feed end of adsorbent vessel 13, the valves operate according to the following schedule.

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Step	Valve number					
	3	9	17	29	31	33
Adsorption	open	open	open	closed	closed	closed
Evacuation	closed	closed	closed	open	open	closed
Pressurization	closed	open	open	closed	closed	open

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The process described above is well-suited for the separation of air, preferably to produce an oxygen product containing 50 to 95 mole% oxygen. The process can be used for the separation of other gas mixtures for applications in which moderate product recovery and/or purity are acceptable.

55 Thus the present invention provides an improvement to a single-bed pressure swing adsorption process and system in which the time required for adsorber pressurization is reduced by pressurizing the adsorber simultaneously from both the feed end and the product end. In a preferred mode of operation, the feed blower transfers pressurization gas

to the feed end of the adsorber from the gas product storage tank. The preferred dual-end pressurization of the present invention allows rapid pressurization and minimizes the duration of this step, thereby improving the overall efficiency of the PSA system.

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Claims

1. A pressure swing adsorption process for the separation of a pressurized feed gas mixture containing at least one more strongly adsorbable component and at least one less strongly adsorbable component comprising the steps of:

- 10 (a) introducing the pressurized feed gas mixture into a feed end of an adsorber vessel containing a solid adsorbent which preferentially adsorbs the more strongly adsorbable component, withdrawing from a product end of the adsorber vessel an adsorber effluent enriched in the less strongly adsorbable component, passing the adsorber effluent into a gas storage vessel, and withdrawing from the gas storage vessel a product stream enriched in the less strongly adsorbable component;
- 15 (b) terminating step (a) and depressurizing the adsorber vessel by withdrawing therefrom a depressurization gas enriched in the more strongly adsorbable component;
- (c) pressurizing the adsorber vessel; and
- 20 (d) repeating steps (a) through (c) in a cyclic manner,

characterized in that the adsorber vessel is pressurized by introducing gas from the gas storage vessel into the feed end and the product end of the adsorber vessel.

25 2. A process of Claim 1, wherein the feed gas mixture is air, the more strongly adsorbable component is nitrogen, and the less strongly adsorbable component is oxygen.

30 3. A process of Claim 2, wherein the solid adsorbent is selected from NaX, NaA, CaX, or CaA zeolite.

35 4. A process of any one of the preceding claims, wherein the depressurization gas is withdrawn from the feed end of the adsorber vessel.

5. A process of any one of the preceding claims, wherein gas for pressurizing the adsorber vessel is supplied directly from the gas storage vessel.

35 6. A process of Claim 5, wherein the same pump means is used for feed gas compression, and for depressurization and pressurization of the adsorber vessel.

40 7. A process of any one of the preceding claims, wherein gas for pressurizing the adsorber vessel comprises a portion of the product stream enriched in the less strongly adsorbable component.

8. A process of any one of the preceding claims, wherein the pressure in the adsorber vessel during step (a) is between 100 and 700 kPa (15 and 100 psia).

45 9. A process of any one of the preceding claims, wherein the adsorber vessel is depressurized during step (b) to a final pressure of between 1 and 80 kPa (0.15 and 12 psia).

10. A process of any one of the preceding claims, wherein steps (a) through (c) comprise a cycle with a duration of between 30 and 240 seconds.

50 11. A process of any one of the preceding claims, wherein, following step (c), the adsorber vessel is further pressurized by introducing pressurized feed gas into the feed end of the adsorber vessel for a period just prior to the initiation of step (a).

12. A process of any one of the preceding claims, wherein gas from the gas storage vessel is introduced into the product end of the adsorber vessel during at least a portion of the depressurization of the adsorber vessel in step (b).

55 13. A pressure swing adsorption system for the separation of a feed gas mixture (1) containing at least one more strongly adsorbable component and at least one less strongly adsorbable component by a process of Claim 1,

which comprises:

- (a) an adsorber vessel (13) containing a solid adsorbent which preferentially adsorbs the more strongly adsorbable component, wherein the vessel has a feed end and a product end;
- 5 (b) a feed blower (5) and piping means (7,11) for introducing the feed gas mixture into the feed end of the adsorber vessel (13);
- (c) a gas storage tank (21) for receiving adsorber effluent withdrawn from the adsorber vessel (13);
- 10 (d) piping means (23) for withdrawing from the gas storage vessel (21) a product stream enriched in the less strongly adsorbable component;
- (e) piping means (15,19) for transferring adsorber effluent from the product end of the adsorber vessel (13) to the gas storage vessel (21) and for transferring gas from the gas storage vessel (21) into the product end of the adsorber vessel (13);
- (f) piping means (32,7,11; 37,41,11; 43,41,11) for transferring gas from the gas storage vessel (21) into the feed end of the adsorber vessel (13);
- 15 (g) valve means (3,9,17,31,33) for isolating the adsorber vessel (13) from the gas storage vessel (21) and the feed gas mixture (1); and
- (h) piping and valve means (11,30,31,7,29,35) for withdrawing depressurization gas from the adsorber vessel (13).

20 **14.** A pressure swing adsorption system of Claim 13 which further comprises piping and valve means (11,30,31,7,29,35) to enable the use of the feed blower (5) to withdraw depressurization gas from the feed end of the adsorber vessel (13).

25 **15.** A pressure swing adsorption system of Claim 13 or Claim 14 which further comprises piping and valve means (32,33,7,9,11) to enable the use of the feed blower (5) to transfer gas from the gas storage vessel (21) into the feed end of the adsorber vessel (13).

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